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Introduction
Overview of the Report

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SUMMARY

The United States' National Aeronautics and Space Administration (NASA) is dedicated to research and exploration, utilizing the unique qualities of space flight. Specifically, a major mission of NASA is "to open the space frontier by exploring, using, and enabling the development of space and to expand the human experience" (4). As flight time increases and we build outposts such as the International Space Station (ISS), it becomes imperative for both safety and cost to minimize consumables and increase the autonomy of the life support system. By recycling air, water, and other consumables, a closed system can be developed that will increase productivity by reducing mass, power, and volume necessary for human support. This requires NASA to invest in high-leverage technologies.

Technologies emerging from this effort also have wide-ranging applications on Earth. These same technologies can potentially help urban planners faced with increased development and a limited water supply. Earth needs include improved technologies to decrease air and water pollution, an ability to recycle urban water, and improved energy efficiency. Additionally, maintaining good air quality in today's airtight homes, office buildings, and industrial sites is of great concern to public health. There is a continuing need for new technologies to mitigate polluting emissions outdoors from a wide array of sources. The air revitalization technologies developed by NASA life support for extended duration space flight have already been applied to ground-based systems.

As part of this effort, NASA's Advanced Life Support Project develops and tests life support technologies and systems to enhance the success of human space exploration. This volume provides a summary of the engineering, life sciences, human factors and performance, and medical accomplishments during the four closed-chamber tests conducted at NASA/Johnson Space Center, Houston, TX, between 1995 and 1997. This introduction will provide a description and history of the tests. For the purposes of NASA's discussion, the term "closed chamber tests"

refers to studies involving a well-trained team who live and work in an enclosed limited volume, or chamber. The only interactions with the outside of the chamber are through communication tools such as telephones, computers, and video. In all these studies, there is a serious attempt to reduce replenishment of supplies from outside the chamber and to recycle air, water, and other consumables and wastes to the greatest extent possible. This provided a step toward having a high fidelity analog to an autonomous operation necessary for space flight beyond low-Earth orbit. There is a limited exchange of personal items and no exchange of crew members. The crewmembers are responsible for all internal maintenance and repairs.

The term “ life support” refers to the sum of the engineering, medical sciences, and technology utilized to provide air, water, food, thermal control, trash and solid waste management efficiently and effectively. To significantly reduce outside replenishment, NASA has used these chamber tests to focus on finding ways to close off life support systems from the general population, and amenities, and allow the crews to be more autonomous. This promotes development of recycling technologies especially for air and water.

Both the former Soviet Union and the United States utilized closed chamber tests to develop their spacecraft life support systems. These tests included ground-based simulations of the Apollo missions (personal communication, Dr. Joe Kerwin) and Skylab missions (1). General ground-based closed-chamber tests similar to the ones discussed in this volume were completed in 1970 by McDonnell Douglas Astronautics Company, Western Division, Long Beach, California (2). The former Soviet Union had similar ground-based simulations as well as a biologically-based system (3).

Early Ground-Based Chamber Tests – Regenerative Life Support Study by NASA Langley Research Center

An operational 90-day manned test of a regenerative life support system, completed in September 1970, was conducted by the McDonnell Douglas Astronautics Company, Huntington Beach, CA. The focus of that test was an integrated life support system and built on a previous 60-day test in the same chamber. The test chamber was 12 feet in diameter and 40 feet long, with 4,100 cubic feet, a 160 cubic foot airlock, and 2 smaller airlocks which were 18 inches in diameter. The chamber operated at 10 psi with 4 male volunteers. The tested life support systems included air, water, waste, and food. The water and oxygen were totally recycled with no resupply. All expendables, food, chemicals, filters, and spare parts were stored at the beginning of the study with no pass-ins. Complete mass balance was determined and each system and its hardware were evaluated. Environmental monitoring assessment included organic, microbiological and inorganic monitoring of the chamber and water, along with air quality including trace contaminents. Water was analyzed for chemical and microbiological content. Interestingly, $^{238}PuO_2$ was used to produce heat for the water recovery subsystem, and crewmembers routinely handled this system so crew radiation exposure was monitored. Total iodine at 6 ppm was used to prevent microbiological growth in the recycled potable water. All the various monitoring hardware was evaluated for performance. Aspects such as power usage and maintenance were studied. There were several biomedical studies including sleep, exercise-metabolic, medical crew status such as vital signs, body water pools and plasma volume changes, lean body mass, and psychomotor performance with short-term memory studies. Also, the acceptability of the habitat, crew training evaluations, and computer assistance scheduling were evaluated.

A complete report was provided (5) giving the details of all the evaluations. This was a successful study that provided a great deal of understanding of life support systems performance at a total atmospheric pressure of 10 psi, along with important information about crew health in such an enclosed life support system. This study provided confidence that these types of studies could be conducted with safety and reliability of the engineering for life support.

Apollo Ground Based Tests

In order to prepare to fly to the moon, two-closed chamber tests were completed. Dr. Joe Kerwin, a Skylab astronaut, served as a simulation crewmember during these Apollo tests. The following is an excerpt from his report of those tests.

> ***Personal Report by Dr. Kerwin , Skylab Astronaut***
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> *Manned vacuum chamber tests were carried out at Johnson Space Center on two Apollo Command/Service Modules (CSM's), Spacecraft 008 and 2TV-1, in preparation for the actual flights. These tests were operational; that is, their purpose was to test under realistic conditions fully developed systems, rather than to advance the state of the art. The first version of the Apollo spacecraft had a pressure of 5 psi with 100 percent oxygen. The "Achilles' heel" of this system was that before launch the cabin was to be purged with pure oxygen at slightly higher than sea-level pressure (about 15 psi), because the spacecraft reduced its pressure to 5 psi during launch, and air at 5 psi has insufficient oxygen to support human life. But pure oxygen at 15 psi provides an environment conducive to fire, which was the cause of the Apollo fire. The initial or "launch" atmosphere was changed for the second test, which had 60% oxygen and 40% nitrogen at 15 psi. The cabin pressure was allowed to equilibrate to 5 psi once the test began. Replenishment during flight was with oxygen.*
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> *The CSM was one of two manned spacecraft required by the lunar land-*

ing program. In it the crew launched, traveled to lunar orbit, and returned to earth. The Lunar Module carried two of the three crewmembers to the lunar surface and back into lunar orbit. The CSM life support system did not attempt to recycle oxygen, water or any consumable. Although there was no possibility of resupply on flights to the moon, and it was imperative to keep system weight to the absolute minimum, the missions were too short (less than two weeks) to make recycling systems feasible. The CSM was small, with only 310 ft^3 *of pressurized volume.*

The first full up test took place October 26 until November 1, 1966. In the first major test there were numerous and significant failures, both large and small. The urine dump system froze, the suit leaked cabin air into the suits, coolant pumps failed repeatedly, excessive moisture condensed on the inside of what became a very cold spacecraft, and numerous valves failed and/or broke. All of the fuel cells flooded and two failed immediately, the third after four days. The test finished using ground power. During this test the crewmembers wore a biomedical vest and exercised with an ergometer.

Pump down for second test commenced at 1430 hours on June 16, 1968, and the spacecraft was, as the crew invitation said, launched into the world's first constant-latitude orbit at 58 feet mean sea level, the altitude of Johnson Space Center, Houston, Chamber A, Building 32. Repress was complete at 0630 on June 24, 184 hours later. This test was very successful and gave data to support the Apollo program. Both cabin and suits provided an acceptable environment, with a robustness that later helped save the crew's life when called upon in Apollo 13.

Some biomedical procedures were completed including before and after flight cardiovascular assessment (exercise tolerance) and body fluid analysis; atmosphere sampling for trace contaminants; potable water servicing and testing to assess the adequacy of the chlorination scheme; dietary assessment; and those portions of the hematology, microbial monitoring and immunology tests which were approved for subsequent flights. These were done to gather baseline data against which to assess flight changes. It is noteworthy that, in the 33 years subsequent to this test, in both ground based and flight experiences, it has never been concluded that the reduced cabin pressure had any significant effect on the crew's physiological response or other biological systems such as microbiological treatment of water.

The Skylab Medical Experiments Altitude Test (SMEAT)

By the 1970s, NASA was committed to an orbiting space laboratory, Skylab. In order to prepare for these intense biomedically-focused space flights, a ground-based simulation was completed. The Skylab Medical Experiments Altitude Test (SMEAT), conducted at NASA/Johnson Space Center, was a 56-day ground-base simulation of a Skylab mission. This test provided a "full-up dress rehearsal" for the 3 Skylab biomedical complement of studies. Unlike the 90-day Langley Research Center test, the three crewmembers were astronauts. The atmosphere was similar to Skylab at 5 psi, 70 percent oxygen and 30 percent nitrogen. The goal of this test was to simulate as much as possible a Skylab 56-day mission including science activities, training, data collection, crew issues, flight equipment, and learning about medical operations and crew health. This test was conducted with two-floor configuration in the same 20-foot diameter and height chamber utilized in three of the four tests reported in this volume. The SMEAT chamber had similar water and waste management systems as Skylab, including a collapsible shower, and ability to collect urine and stool samples. The lighting and food systems were identical to those on the Skylab station. Air monitoring hardware was tested including a carbon dioxide/dew point monitor. A cryotrap system was used to sample gas returning to the air conditioning return duct. This provided data on 25 compounds found in the atmosphere. Tests of the urine system demonstrated specific problems, such as being too small, resulting in redesign for Skylab flight systems. Life sciences experiments conducted were also similar to those for Skylab: lower body negative pressure, vectorcardiogram, bone mineral levels, metabolic activities, blood and urine parameters, crew microbiology, oral health, habitability/crew quarters, crew training, as well as specific hardware tests. With this test, there was increased confidence that the Skylab biomedical research could be completed successfully: A correct conclusion.

The Next Generation of Life Support Studies

This volume provides a summary of the results of individual projects from the four chamber studies conducted from 1995 through 1997. The outcomes from the many chamber tests conducted provide a good model for future long-duration space flight and operational experiences with the technologies and protocols that will be used in space flight. Furthermore, these operational tests demonstrate technologies that may reach the terrestrial commercial market. The four tests described in this volume had very different specific advanced life support objectives as described in the overview chapter of this report. In general, these tests were focused on engineering life support systems with humans-in-the-loop. Although some aspects of human activity can be simulated by metabolic simulators, the integration with humans eventually must be tested. Metabolic simulators are not able to fully test the advanced life support systems.

The book begins with the crewmembers' and medical officer's observations. It is clear that the crewmembers were committed to providing a very successful set of tests. These crewmembers were selected from volunteers, and represented engineering and life sciences specialties needed to conduct the tests. A medical officer was assigned to evaluate the crewmember's health before, during and after the test. As seen by the description, there was constant interface with the crewmembers and their families throughout the test to ensure their physical and psychological health.

Dr. Henninger, the chief scientist for these 4 tests, provides an overview to the life support studies. This is followed by a section on human factors/behavior and performance. Within the section is a description of the internal configuration of the 20-foot chamber to make it an effective tool for life support studies, and to provide the crew with a safe habitable environment. Under the environmental section, there is a description of air, water, and microbiological monitoring results. The food system was different for each test and it is described also. The two last sections summarize the biomedical experiments and training studies completed. These four tests involved many disciplines, aerospace companies, and university support.

Phase I

The goal of the Phase I test was to demonstrate the use of higher plants to provide the air revitalization to meet the oxygen requirements of a single test subject. A primary objective of the test was to demonstrate how a wheat crop could continuously provide the CO_2 removal and O_2 generation required for a single human test subject for 15 days. Air quality was determined through out the study including trace contaminant control. The test also demonstrated that plants could be utilized to control the O_2 and CO_2 concentrations in human-habited systems.

Phase II

The Phase II test was a 30-day, four-person test completed in the 20-foot diameter chamber. The purpose of the test was to verify performance of integrated physicochemical (P/C) life support system technologies for air revitalization, water recovery, and thermal control as an integrated life support system, capable of sustaining a crew of four for 30 days. This required demonstrating the air revitalization system, a water recovery system to successfully produce potable water from hygiene water (shower, hand wash, laundry), urine, and humidity condensate, and an effective active thermal control subsystem. Psychological, human factors, and studies on the microbiological environment were conducted.

Phase IIa

The Phase IIa test was a 60-day, four-person test completed with U.S.-provided life support subsystems functionally similar to that on the International Space Station. The purpose of the test was to verify integrated performance of baselined ISS life support technologies for air revitalization and water recovery and to provide additional integrated test data to the Advanced Life Support Test Project. ISS-like hardware representing significant advances in state-of-the-art life support capabilities emulated the flight hardware and provided integrated data to the ISS Program. All life support systems were monitored and biomedical tests were completed with the four crewmembers.

Phase III

The final test was the Phase III test which incorporated the use of biological systems and physicochemical life support system technologies to continuously recycle air, water, and part of the solid waste stream generated by a four-person crew for 91 days. In the chamber, lettuce was grown and bread from wheat grown in a nearby chamber was baked into bread. These additional activities taxed the air revitalization system. This 91-day test had the most complete set of biomedical studies with a closed ground-based system, of any closed chamber tests. Data from these tests have been used to provide better habitability and health to the crew systems for ISS.

These four tests successfully accomplished many engineering, medical, and scientific goals: those accomplishments are reported in this volume (see Table 1.2-1).

Table 1.2-1 *Timing of the experiments which took place during the Lunar-Mars Life Support Test Project*

Chapter	**Phase I (15-Day)**	**Phase II (30-Day)**	**Phase IIa (60-Day)**	**Phase III (91-Day)**
2.1 Test Phases and Major Findings	x	x	x	x
2.2 Chamber Studies Medical Care Overview: Officer's Report	x	x	x	x
3.1 Architecture		x	x	x
3.2 Habitability: an Evaluation		x	x	x
3.3 Acoustic Noise			x	x
3.4 Assessment of Sleep Dynamics in a Simulated Space Station Environment			x	x
3.5 Operational Psychology		x	x	x
3.6 Spaceflight Cognitive Assessment Tool				x
3.7 Sociokinetic Analysis as a Tool for Optimization of Environmental Design			x	x
4.1 Air Quality	x	x	x	x
4.2 Water Chemistry Monitoring	x	x	x	x
4.3 Microbiology	x	x	x	x
4.4 Crew Food Systems		x	x	x
5.1 Nutritional Status Assessment			x	x
5.2 Exercise Countermeasures Demonstration Project			x	x
5.3 Reactivation of Latent Viruses			x	x
5.4 The Influence of Environmental Stress on Cell-Mediated Immune Function				x
5.5 Physiological Effects of Iodinated Water on Thyroid Function		x	x	x
6.1 Telemedicine				x
6.2 In Situ Training Project			x	x

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